

**REPORT DOCUMENTATION PAGE**Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

<b>1. REPORT DATE (DD-MM-YYYY)</b> 20-03-03		<b>2. REPORT TYPE</b> Final		<b>3. DATES COVERED (From - To)</b> 01-01-2000 to 31-12-2002	
<b>4. TITLE AND SUBTITLE</b>  A Finescale Lagrangian Instrument System				<b>5a. CONTRACT NUMBER</b>	
				<b>5b. GRANT NUMBER</b> N00014-01-1-0163	
				<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b>  John M. Toole				<b>5d. PROJECT NUMBER</b>	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  Dept. of Physical Oceanography, MS.21 Woods Hole Oceanographic Institution Woods Hole, MA 02543				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> Office of Naval Research Regional Office, Boston 495 Summer Street, Room 627 Boston, MA 02210-2109  Attn: Dr. Steve Murray Processes and Prediction Division Code 322PO, Ballston Tower One 800 North Quincy Street Arlington, VA 22217-5650				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>  ONR 322PO	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b>  "Approved for Public Release; Distribution is Unlimited."					
<b>13. SUPPLEMENTARY NOTES</b>  None					
<b>14. ABSTRACT</b>  A new deployment scheme for the Moored Profiler instrument in which the vehicle cycles along a freely-drifting tether was designed and field tested. The goal of the drifting tether system is to acquire finescale temporal information that is less contaminated by Doppler shifting by the large-scale background flow than is achievable from conventional, bottom-anchored moorings. An initial trial of the concept targeting the upper ocean was carried out off Bermuda in November 2001 with an instrument profiling between 12 and 280-m depth. The resultant temperature and salinity data were of good quality and clearly documented diurnal stratification changes at the surface. Individual velocity profile data exhibited significant "noise" in the upper 75 m due to surface wave motions; at greater depth this noise was greatly reduced. And despite the wave noise, inertial oscillations in the surface mixed layer were clearly evident after modest temporal and depth filtering. Based on this successful trial, plans have been made to use the instrument system in an upcoming study of deep winter convection and Eighteen Degree Water formation.					
<b>15. SUBJECT TERMS</b>  Finestructure, Air-Sea Interaction					
<b>16. SECURITY CLASSIFICATION OF:</b>  Unclassified			<b>17. LIMITATION OF ABSTRACT</b>  UU	<b>18. NUMBER OF PAGES</b>  9	<b>19a. NAME OF RESPONSIBLE PERSON</b> Dr. John M. Toole
<b>a. REPORT</b>	<b>b. ABSTRACT</b>	<b>c. THIS PAGE</b>			<b>19b. TELEPHONE NUMBER (include area code)</b> 508-289-2531

20030331 037

## **A Finescale Lagrangian Instrument System**

John M. Toole, Principal Investigator

Department of Physical Oceanography MS #21

Woods Hole Oceanographic Institution

Woods Hole, MA 02543

ph: (508) 289-2531 fax: (508) 457-2181 email: jtoole@whoi.edu

Award Number: N00014-01-1-0163

Period of Performance: January 1, 2001 to December 31, 2002

Amount Awarded: \$53,009

### **LONG-TERM GOALS**

One of the long-term goals of my research is to understand the processes that control diapycnal mixing in the ocean (with particular emphasis on the turbulence supported by internal wavebreaking). I also wish to understand the consequences of mixing for the ocean's general circulation.

### **OBJECTIVES**

Our recent work has revealed strong relationships between internal wave energy levels and the intensity of turbulent mixing in the ocean interior, with evidence for enhanced internal wave and turbulence levels in proximity to irregular bottom topography and within gravity currents downstream from bathymetric sills. Distorted/enhanced internal wave fields and elevated levels of mixing have also been observed near the ocean's free surface. Quantifying the characteristics of the finescale motions in these domains has proven difficult using conventional (bottom-anchored) instrumentation owing in part to the complicating aspect of horizontal advection. The present grant supported the design and testing of a new deployment scheme for the Moored Profiler instrument in which the Profiler operates on a freely-drifting vertical tether. Finescale velocity, temperature, and salinity observations in a Lagrangian framework obtained by the new measurement system will help us better diagnose the physical processes driving the mixing in these regions. The immediate objective of this research program was to quantify the behavior of the Moored Profiler instrument in this new deployment configuration to determine if it will be appropriate for future scientific investigations.

### **APPROACH**

Over the last 10 years with support from the National Science Foundation, the Office of Naval Research, and the National Oceanic and Atmospheric Administration, we developed a new autonomous instrument able to repeatedly traverse a vertical mooring wire carrying sensors through the water column: the Moored Profiler (MP: Doherty *et al.*, 1999; Toole *et al.*, 1999; Morrison *et al.*, 2000; 2001). Prototype MP instruments fitted with a CTD for measuring ocean temperature and salinity *versus* pressure, and an acoustic current meter (ACM) that measures the 3-D ocean velocity, were first deployed in support of science during our Littoral Internal Wave Initiative TWIST experiment (Turbulence and Waves over Irregular Sloping Topography) in 1998 (Nash *et al.*, 2003). Since that time, the Moored Profiler has become an operational instrument within the Woods Hole Oceanographic Institution Physical Oceanographic Observations Laboratory (POOL).

In our analyses of Moored Profiler data, we have on occasion found that the effects of horizontal advection make interpretation of the finescale motions difficult. For example, internal lee waves

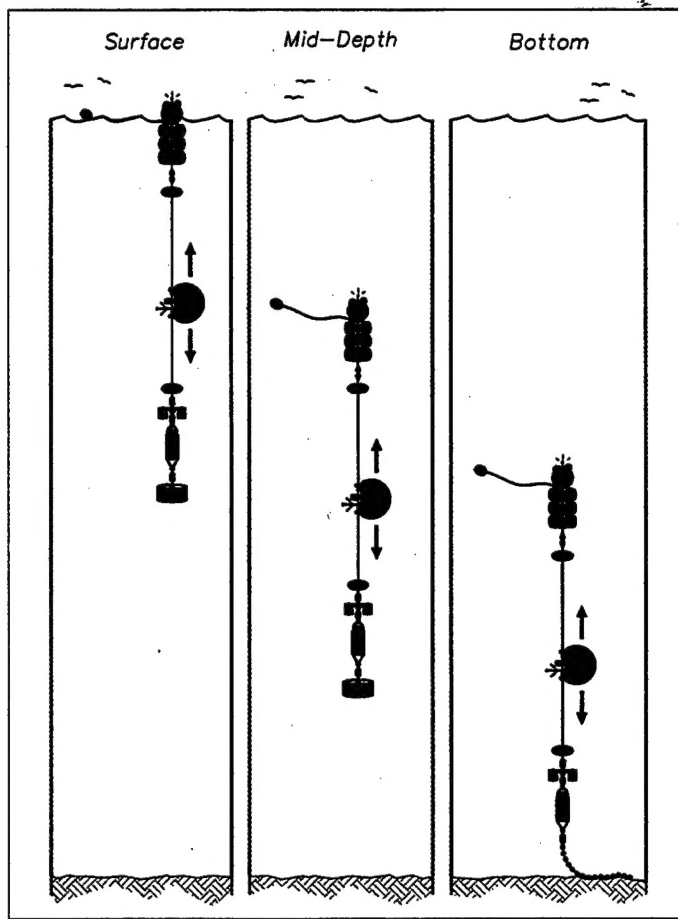


Figure 1: Schematic drawing of three possible deployment modes for the Finescale Lagrangian Instrument System (FILIS).

appear stationary in a coordinate system fixed to the ocean floor, and are thus missed in the usual finescale analysis approach of studying anomalies from time means. A more natural coordinate system to observe finescale motions is one that moves with the local water column. The present grant supported testing and evaluation of a new deployment scheme for the Moored Profiler in which the vehicle cycles up and down a freely-drifting vertical tether. We call this assembly the Finescale Lagrangian Instrument System (FILIS). Three deployment modes are imagined for the FILIS, targeting study of the surface ocean, the stratified interior, and abyssal flows (Figure 1). With the support of the present grant, we designed, constructed, and field-tested the surface ocean version.

## TASKS COMPLETED

For the initial proof of concept, we opted to evaluate the surface ocean version of the FILIS. Surface wave motions present the major design hurdle for this configuration. The MP was originally designed for use on subsurface moorings, and we were not sure if it would function on a tether subjected to high-frequency heave. To decouple the tether from surface wave heave and minimize such motions,

the test system employed small, distributed buoyancy elements above the main flotation to maintain the profiling segment just below the surface (Figure 2). The tether segment that the MP traveled along was conventional plastic-jacketed wire rope, held vertical by a 500-pound ballast weight and the compensating array of buoyancy spheres. Buoyancy and ballast were adjusted so that the full tether arrangement was nearly neutral (a few pounds negative). The buoyancy provided by one of the floats shown in the figure was more than sufficient to hold the complete system just below the surface. The small surface buoy at the end of the surface tether facilitated tracking the FILIS during its deployment.

The theoretical performance of the FILIS in response to an assumed distribution of surface waves was explored by Dan Frye and Jason Gobat through application of a state-of-the-art mooring dynamics program (Gobat and Grosenbaugh, 2000). That study suggested vertical motions at the base of the 300-m tether in response to a random wave field with eight-foot significant height and 9-s dominant period should be less than 40 cm. The model analysis also predicted that the horizontal velocity of the tether just below the flotation in these wave conditions is  $\pm 50$  cm/s, but that this motion decreases rapidly with depth and is negligible at the sinker weight.

For the field test we used an upgraded version of the prototype Moored Profiler previously deployed in the LIWI-TWIST experiment (Figure 3). The original controller and hard disk data logger were replaced by the electronics used in the commercially available version of the instrument (manufactured under license by McLane Research Laboratories, Inc.) The new controller supports a more capable sampling program and archives data to a flash memory pcmcia card which is easily ported to laptop computers for data offloading. The controller change also necessitated upgrade of the ACM. These modifications to the MP, carried out by WHOI technician Steve Liberatore, were subsequently tested and validated with short deployments under the WHOI pier.

A field trial of the FILIS system was carried out in November 2001 from the R/V *Weatherbird* offshore from Bermuda. The test was done in conjunction with a regularly scheduled cruise to deploy a drifting sediment trap as part of the Bermuda Atlantic Time Series program (BATS, Michaels and Knap, 1996). One WHOI technician (Scott Worrirow) joined this trip to deploy and recover the FILIS on a not-to-interfere basis. The system was deployed late on November 8, 2001 with an sampling program calling for continuous profiling between 12 and 280 dbars beginning at 0000 GMT on the 9th. The instrument performed well, completing 69 profiles (approximately two profiles per hour) before recovery around 1200 GMT on the 10th. Leading up to the cruise, strong winds and large seas buffeted Bermuda, delaying the scheduled departure date by several days. During the trial, winds had relaxed to 10-15 knots out of the northwest supporting wind waves of around 1 m, on top of a 0.6 to 1.2-m swell. Upon recovery of the system, the MP data were offloaded and all equipment return-shipped to Woods Hole, whereupon the data were reduced and analyzed.

## RESULTS

Though short in duration, the FILIS field test demonstrated the viability of this instrument system for future studies of the upper ocean. The distributed buoyancy arrangement appeared to work well; tether heave was limited to less than 1 m peak-to-peak at swell period of 12 seconds with near total suppression of wind-wave motions (Figure 4). The resultant wire motions were well within the operating capability of the Moored Profiler. Importantly, the peak vertical velocity of the tether did not greatly exceed the profile speed of the MP, so that large vehicle reversals (and the sensor

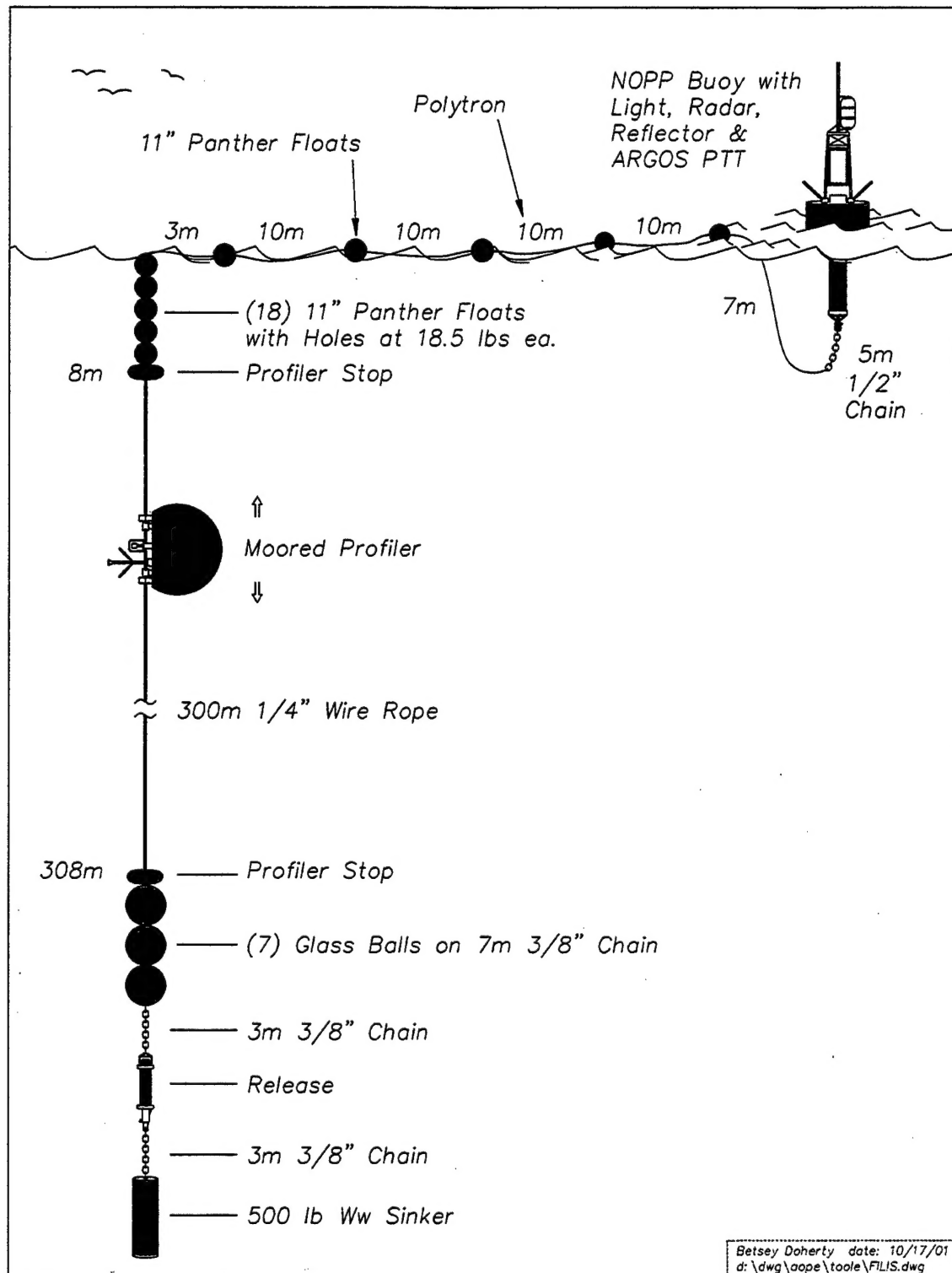


Figure 2: Schematic drawing of the FILIS as deployed offshore from Bermuda in November 2001.

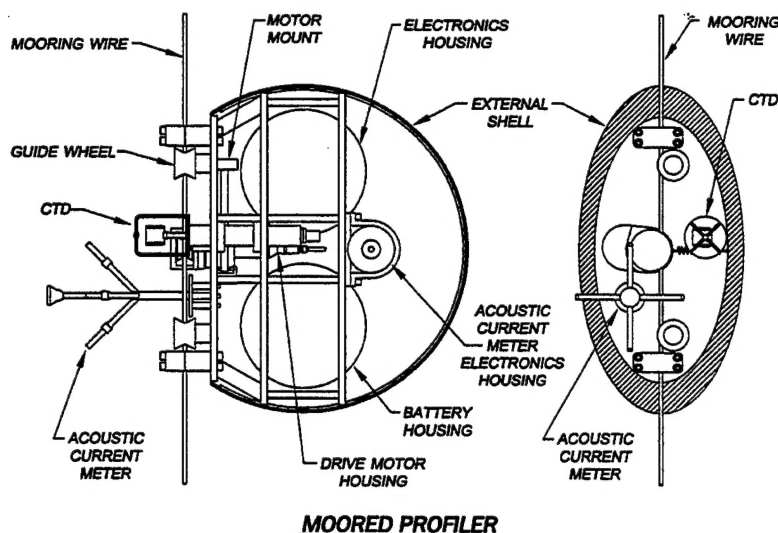


Figure 3: Schematic drawing of the WHOI prototype Moored Profiler (MP) instrument, developed in part with past support from the Office of Naval Research. One of these systems (with upgraded controller electronics) was utilized for the FILIS field trial.

data anomalies that result) were rare. The tether also proved to be quite stiff, thanks to the large buoyancy and ballast weight at either end of the tether. Maximum wire angles from the vertical experienced during the trial were just  $4^\circ$ .

The scalar data logged by the MP (temperature and salinity) were of good quality throughout the profiling depth interval and clearly documented diurnal stratification changes at the surface (Figures 5a,b). Individual velocity profile data exhibited significant "noise" in the upper 50–75 m due to surface-wave motions (Figure 6). At greater depth this noise was much reduced and significant persistence of velocity features, profile-to-profile, were observed in the thermocline. And despite the wave noise, inertial oscillations in the surface mixed layer were clearly evident after modest temporal and depth filtering (Figures 5a,b).

The extended length of the profile wire used in this trial (300 m) combined with the very strong inertial shear between the surface layer and interior challenged the Lagrangian character of the FILIS. As is evident in Figure 6, the instrument had a non-zero drift relative to the depth-average flow over the upper 300 m of the water column (the interval occupied by the FILIS). (Depth-averaged relative velocity for the profiles shown was approximately 8 cm/s, typical of the trial period.) The zero-relative-velocity depth for these profiles was 60 m. Drag and windage of the surface float and tether biased the FILIS drift towards the surface. Relative motion between the FILIS and the waters was responsible for the salinity values in the subsurface maximum varying on inertial time scales seen in Figure 5b. If desired, improved coupling to the mixed layer could be achieved by using a shorter tether. But even in this strongly sheared environment, the FILIS platform reduced relative motion between the surface layer and sensors by a factor of 2 on inertial time scales as compared to a bottom-anchored mooring. Moreover, tracking on longer time scales (where the shear is much reduced) is greatly improved. Indeed, the mean relative velocities over the test deployment period were less than 3 cm/s at all depths sampled.

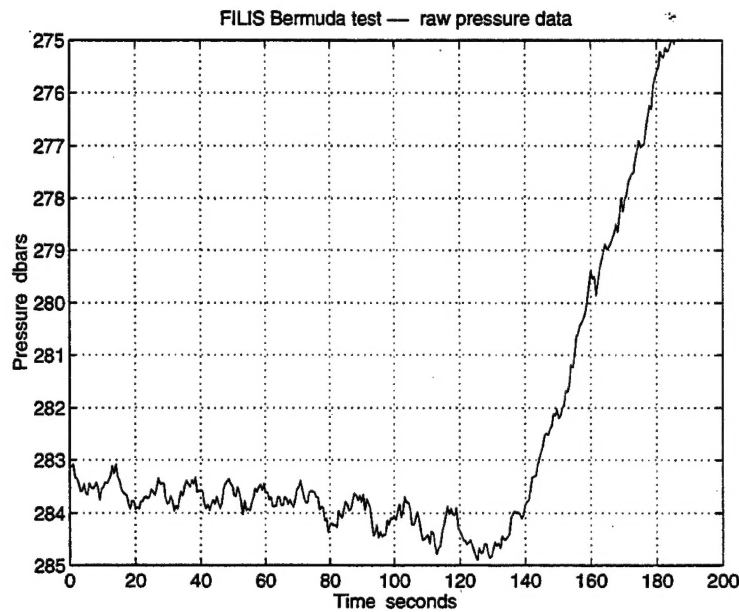


Figure 4: Raw pressure time series data from the MP deployed on the FILIS in November 2001. Shown are observations from an up-going profile. Before initiating each cycle, the MP logs sensor data for two minutes. During this warm-up, pressure oscillations of around 1 m peak-to-peak at 12-second period were sampled: the signature of tether heave due to surface swell acting on the FILIS. These tether motions were sufficiently small and long-period that the vertical progress of the MP rarely reversed (see data after time equals 120 seconds).

A technical note describing the FILIS and its performance is in preparation (Toole *et al.*, 2003).

## IMPACT FOR SCIENCE

With the FILIS now a proven instrument system for examining the time evolution of the upper ocean in response to atmospheric forcing, I am collaborating with Drs. J. Edson, E. Terray and B. Sloyan in planning use of the device in support of a research program to investigate formation mechanisms of Eighteen Degree Water in the eastern subtropical North Atlantic. For this study we envision the FILIS tethered to the Air-Sea Interaction Spar (ASIS) buoy (supporting turbulent atmospheric flux sensors and navigation equipment). We hope to make repeated late-winter deployments of the FILIS/ASIS on the Sargasso-Sea side of the Gulf Stream axis to sample the air-sea fluxes and the time evolution of the upper ocean stratification and circulation. During each drift, local ship-based surveys will be carried out around the drifting instruments.

## RELATIONSHIPS TO OTHER PROGRAMS

The FILIS instrument may be used in support of a host of other programs investigating air-sea interaction and the nature of ocean finestructure.

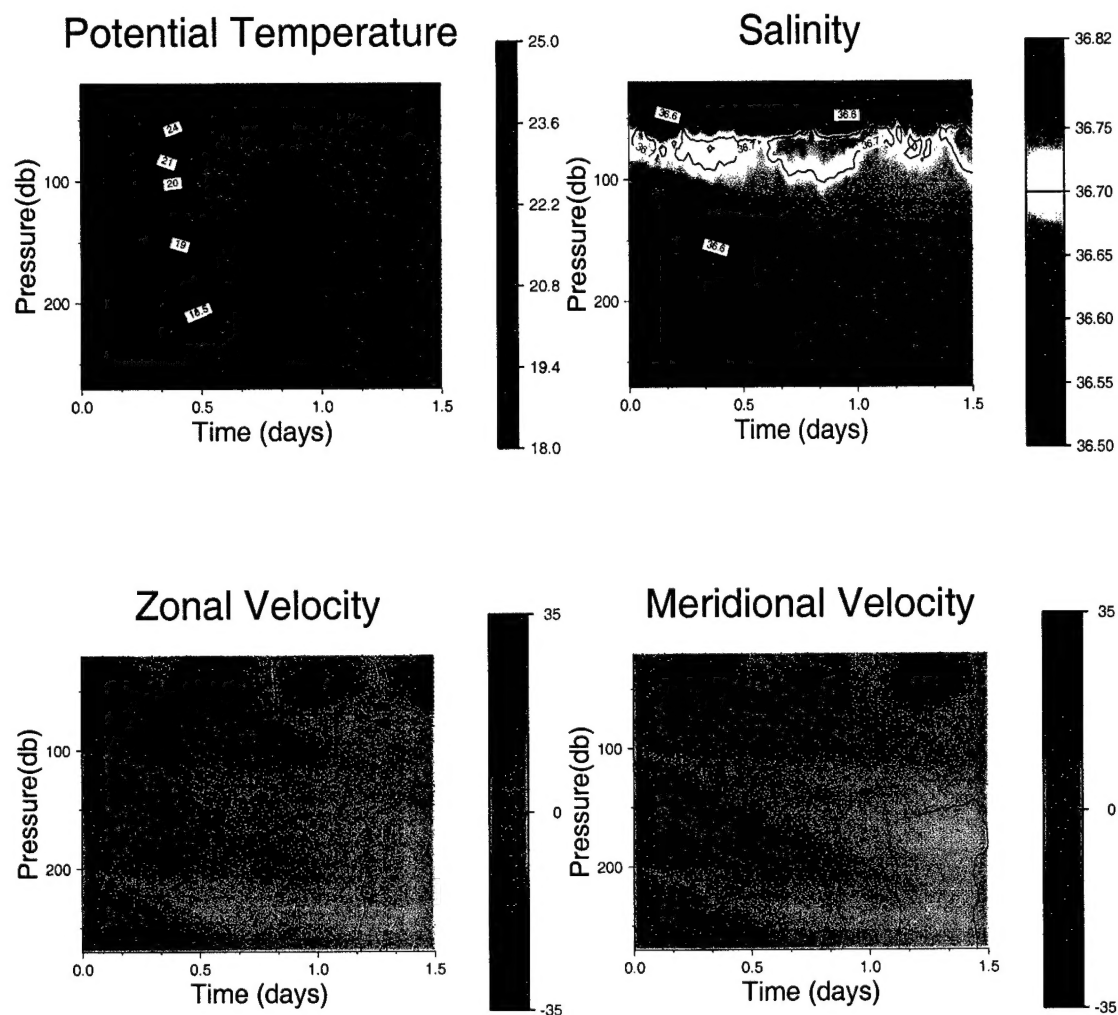


Figure 5: Depth-time contour plots of (a) (upper left) potential temperature (contour interval:  $0.5^{\circ}\text{C}$  below  $20^{\circ}\text{C}$ ,  $1^{\circ}$  between  $20$  and  $24^{\circ}\text{C}$  and  $0.1^{\circ}\text{C}$  above), (b) (upper right) salinity (contour interval:  $0.05$  pss), (c) (lower left) east and (d) (lower right) north velocity (contour interval:  $5$  cm/s) from the FILIS trial deployment offshore from Bermuda. Data were binned at 30-minutes and 5 dbars before contouring. Velocity data are shown relative to the depth-averaged flow between 100 and 200 m.

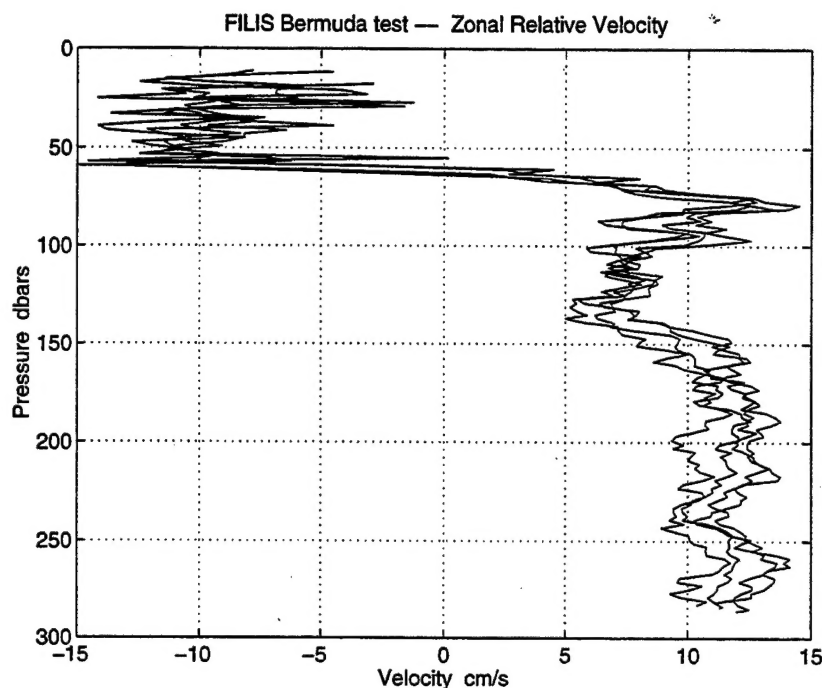


Figure 6: Raw zonal relative velocity profiles from four successive profiles of the MP during the FILIS trial. Profiles were acquired approximately every 30 minutes. Note the noisy signals in the upper 50 m due to surface wave motions that are much reduced at depth where finescale structures were repeatedly resolved on successive profiles.

## REFERENCES and RELATED PUBLICATIONS

- Doherty, K. W., D. E. Frye, S. P. Liberatore, and J. M. Toole, 1999. A moored profiling instrument. *Journal of Atmospheric and Oceanic Technology*, **16**, 1816–1829.
- Gobat, J. I. and M. A. Grosenbaugh, 2000. WHOI Cable v2.0: Time Domain Numerical Simulation of Moored and Towed Oceanographic Systems. *Woods Hole Oceanographic Institution Technical Report*, WHOI-2000-08, 85 pp.
- Michaels, A. F., and A. H. Knap, 1996. Overview of the U.S. JGOFS Bermuda Atlantic Time-Series study and the Hydrostation S program. *Deep-Sea Research, Part II*, **43**, 157–198.
- Morrison, A. T. III, J. D. Billings, K. W. Doherty, and J. M. Toole, 2000. The McLane Moored Profiler: A Platform for Physical, Biological, and Chemical Oceanographic Measurements. *Proceedings of the Oceanology International 2000 Conference* March 7–10, 2000, Brighton, UK.
- Morrison, A. T., J. M. Toole, R. Lukas, S. E. WorriLOW, and K. W. Doherty, 2001. Results from the first successful field deployment of the McLane Moored Profiler. *Proceedings of MTS Oceans 2001 Meeting*, Hawaii, November, in press.

- Nash, J. D., E. Kunze, J. M. Toole and R. W. Schmitt, 2003. Internal tide reflection and turbulent mixing on the continental slope. *Journal of Physical Oceanography*, in preparation.
- Toole, J. M., K. W. Doherty, D. E. Frye, and S. P. Liberatore, 1999. Velocity measurements from a moored profiling instrument. *Proceedings of IEEE Sixth Working Conference on Current Measurement*, March 11–13, 1999, San Diego, pp. 144–149.
- Toole, J. M., D. E. Frye and S.E. Worriow, 2003. The Finescale Lagrangian Instrument System, in preparation.